No-till Farming: Agronomic Intervention through Cover Cropping for Enhancing Crop Productivity

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Abstract

Tillage disturbs the soil and causes soil erosion. Various conservation tillage mechanisms are undertaken to reduce erosion, and one such is no-till. No-till (NT) is the method by which crops are raised every year without disturbing the soil. The advent of machinery that helps drilling in either through crop residues or cover crop mulch has helped reduce soil erosion and increased the spread of NT farming. The impact of NT on increasing crop yields has been researched upon with varying results. The adoption incentive is always increased yield for the producer, and cover cropping is one major recommendation for yield improvements through NT. Cover crops can be grown as sole crop or a mixture to enable exploiting different layers of the soil, help fixing atmospheric nitrogen, improve soil nutrient status, improve soil porosity, and, above all, produce maximum biomass to help build the soil and prevent erosion. Cover crops as a feature in organic or conventional rotations must be thought as to why and where they fit into the rotation. Planting and termination dates have to be coordinated between the cover crop and chosen cash crop so that they do no overlap but have a wide enough growth window. It is important for the cover crop to produce maximum biomass, but the cash crop must also be planted at the right time for the critical yield to be maintained or improved. Research that is innovative and balances

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conservation of soil with increased crop yields should be the best serving option that needs to be developed, and it is fairly obvious to turn to cover cropping.

Keywords

No-till · Cover crops · Soil properties · Crop productivity

3.1 Introduction

Tillage, in simple terms, is the process of opening up the soil for planting of the crop, the first or in sequence, and is practiced on most agricultural lands around the world. However, tillage is a leading cause for erosion of farm soil as it destroys soil aggregates making soils more prone to erosion. There are many different tillage methods: conventional, conservation, ridge, strip, and vertical, with another option of no tillage at all. No till? What would that be, and why would that option be interesting to producers?

"No-till" is the method by which crops are raised each year without disturbing the soil at all. In other words, it can be described as a method whereby crops are cultivated without carrying out the plowing or tillage operations "considered necessary" for establishing a good crop stand and environment. The crop is sown by drilling either in to crop residues or in a cover crop mulch without opening the soil. It minimizes or reduces the soil disturbance, thereby drastically reducing soil erosion. It also reduces the release of carbon dioxide, a greenhouse gas into the atmosphere, which happens due to intensive tillage practices. Not breaking the soil leads to buildup of soil organic matter, improved water holding capacity, higher nutrient availability, and the release of nutrients for crop growth (Blanco-Canqui et al. 2015; Vincent-Caboud et al. 2017).

3.2 "No-till" as a Concept

How did this concept come to be? Since turning to agriculture, human history points to the plowing of the land for sowing and crop cultivation. The advent of machinery made it much easier to continue tilling the land (Margulies 2012). However, the loss of fertile soil from farm lands due to erosion, caused in part from the breaking of soil particles, and the eventual problems it created made people begin to take notice of the effects of tillage. Also, the arrival of herbicides for the control of weeds, which previously needed a turn of the soil for control, and the invention of seed drills which could plant the seeds without opening up the soil set the move towards no-till farming. With more machinery and advancement of technology to carry out specific farm practices, no-till seemed like a good option to harvest the abovementioned benefits and achieve environmental rehabilitation, provided there was no compromise on the crop yields recorded. Though the benefits of NT are many, producers farm for profit, and they must see an economic incentive to follow any practice that allows for environmental rehabilitation. Adoption of NT also brings about financial saving, along with saving in labor and fuel costs. A UNEP report (Neufeldt 2013) cited Lorenzatti (2006) in Argentina that while a liter of fuel could produce 50 kg of grain under conventional tillage, it would be 123 kg under no-till farming (from UNEP 2013). The benefits of no-till farming can build over years.

No-till (NT) farming is spreading around the world across diverse ecosystems and production systems. Adoption has been faster in the USA compared to other countries, and it has led to a drastic reduction in farmland erosion over decades. In 1962, Harry Young Jr. was recorded as the first farmer to grow corn without tillage in the USA (Coughenour and Chamala 2000). Between 1982 and 1997, overall cropland erosion dropped by more than a third in the USA, where policy interventions to promote NT practices on highly erodible land contributed up to 62% of the overall reductions, from 3.1 billion tonnes of soil in 1982 to 1.9 billion tonnes in 1997 (Claassen 2012). The share of total conservation tillage that is NT also varied from 67% (45% of total acreage) for wheat in 2017, 56% (40% of total acreage) for soybeans in 2012, 44% (18% of total acreage) for cotton in 2015, and 42% (27% of total acreage) for corn in 2016 (Claassen et al. 2018). Continuous NT has been adopted across 21% of all cultivated cropland acres in the USA (Creech 2017).

Neufeldt (2013) also reported that NT agriculture increased in Australia from 9% of cropland in 1990 to 74% in 2010. In the countries of Argentina, Brazil, Paraguay, and Uruguay, the highest rates of NT cultivation cover 70% of total cultivated area, two-thirds of which are under permanent NT schemes, resulting in significantly increased soil carbon storage (Derpsch et al. 2010). Conservation agriculture (CA) that comprises of no or minimum mechanical soil disturbance, biomass mulch soil cover, and crop species diversification was reported in 78 countries in 2015–2016, an increase in adoption by 42 more countries since 2008–2009, respectively (Kassam et al. 2018). Many other countries opt for no-till, but not under a permanent system which reduces the effectiveness and accrued benefits under no-till.

3.3 No-till and Adoption Incentives

No-till practices reverse the occurrences under tillage by minimizing mechanical soil disturbance, providing permanent soil cover, and diversifying crop species grown in sequence and/or association (FAO 2013). Keeping a residue on the soil surface breaks the impact of the raindrops and helps soil to stay in place and prevent erosion. To transition from conventional farming to NT, many a times, there is need for government intervention and support through policy changes. This transition is a costly process as there is a need to invest in heavy machinery/ equipment and also can create an overdependence on plant protection chemicals and herbicides. In the USA, many farmers are “partial” adopters, adopting these conservation practices in some but not all of their acres. Roughly 40% of combined acreage of corn, soybean, wheat, and cotton were in no-till/strip till in 2010–2011, with adoption rates higher for some crops (e.g., soybean) and some regions (USDA ERS 2017). Federal government subsidies toward adoption of such conservation practices give incentives for farmers to switch to these practices (Plumer 2013). Cropping system, rainfall intensity and frequency, slope, and the soil of the locality all decide the success of NT farming in minimizing soil loss by erosion. Montgomery (2007) (as reviewed by Margulies 2012) reviewed 39 studies comparing NT and conventional tillage (CT) practices on soil erosion, and found no-till practices to reduce soil erosion rates by up to 98%, including long-term experiments with NT corn plantings. Overall cropland erosion dropped in the USA by adoption of NT practices (Claassen 2012).

Other incentives towards adoption of no-till conservation practice would be enhanced crop yields (increased benefits realized above the cost savings), increased soil organic matter (SOM) and water retention. Production increases are not expected from area increases but from yield increases (Friedrich and Kassam 2016), and so it is important to achieve that from NT if we want to see greater adoption of NT.

Reduction in the short-term crop yield is one major barrier for farmers considering adoption of NT system. However, considering the ecosystem services of NT, maintaining crop yields at or above optimum production levels could also serve as an incentive. What are the interventions that could be carried out in a NT that would result in such production? Increasing the availability of nutrients that enable crop growth and improving the SOM could be a sure path to enhancing crop productivity through diversification of crops, adoption of crop rotations, and cover cropping. The other environmental benefits that accrue add up over time to increase crop yields in the future.

3.4 Crop Yields in Relation to no-till

Profit is probably the most important factor influencing the adoption behavior of farmers with respect to conservation agriculture practices such as NT, reduced tillage coupled with stubble retention (Cary and Wilkinson 1997). Farmers show greater interest in alternative production practices that show yield response. Many researchers have shown increase in crop yields with no-tillage, while few others have shown the converse to be true. Studies have shown that different crops respond differently to climatic and soil parameters in NT systems. Vyn and Raimbault (1993) indicated a yield decline of corn in NT after initial 8 years, while Beyaert et al. (2002) have reported a no effect on yield.

Pittelkow et al. (2014) observed that conservation agriculture (CA), in its approach to manage agro-ecosystems for improved and sustained productivity, represents a set of three crop management principles: (1) direct planting of crops with minimum soil disturbance (i.e., NT/minimum/reduced tillage), (2) permanent soil cover by crop residues or cover crops, and (3) diversified crop system/rotation. However, the perception that exists among producers is that NT generally reduces crop yields and lower economic returns except on well-drained soils and highly sloped and erodible lands (Triplett and Dick 2008; Pittelkow et al. 2015). Grandy et al. (2006) reported that there were no crop yield trade-offs due to the differences in tillage conditions in soybean and corn in a long-term tillage study in Michigan. They reported that although agronomic challenges exist in NT, over a longer period of time, the yield in these systems can equal or exceed tilled systems. Similarly, in a study over 9 years in Maryland, Cavigelli et al. (2008) reported similar average corn yield between NT and CT (7.88 and 8.03 Mg ha^{-1}, respectively). Cook and Trlica (2016) and Karlen et al. (2013) have also reported similar results in their studies.

From their meta-analysis comparing various tillage practices along with their yield, Pittelkow et al. (2014) found that NT negatively impacted crop yields by 5.7%, although under certain conditions it produced yields equivalent to or greater than CT systems. But certainly, yield is only one component of agricultural systems, and there is an urgent need to optimize farming practices across other environmental and socioeconomic indicators. Importantly, the negative impacts of NT are minimized when all the other CA principles are also applied simultaneously (22.5%). The largest yield declines occur when NT is implemented alone (29.9%) or with only one other CA principle (25.2% and 26.2% for residue retention and crop rotation, respectively). To help close the yield gap with CT, these findings suggest that instead of implementing NT as the first step toward CA in cropping systems where residue retention and crop rotation are absent (and anticipating that these two principles will follow in time), the primary focus should be on implementing NT systems that already include the other two principles.

Cook and Trlica (2016) reported from their study that NT yielded less than tilled soil (corn and soybean) when the soil test values were lower than recommended level and that NT with NPK management may allow farmers to maintain high yields while reducing soil and nutrient losses. In a more recent publication, Trlica et al. (2017) concluded from a long-term experiment since 1991 that NT and CT have carried the same potential for profit as other tillage systems under full fertility management.

In Iowa, Al Kaisi and Yin (2004) found that NT yielded as much or more than other tillage methods under corn-soybean rotation, while a survey of Illinois farmers found that most conservation tillage systems (NT, reduced till, ridge till, or mulch till) had higher profits than CT due to reduced costs involved (Liu and Duffy 1996). DeFelice et al. (2014) made an extensive study of corn and soybean research that compared yields of NT and CT systems in the USA, and they found that NT tended to have greater yields (about 12% more) than CT in the south and west regions. The two tillage systems had similar yields in the central USA, and NT typically produced lower yields than CT in the northern USA and Canada. No-tillage had greater corn and soybean yields than CT on moderate to well-drained soils, and the yields tended to benefit from crop rotation in NT. Similarly, Toliver et al. (2012) evaluated yields from 442 paired tillage experiments across the USA along with the environmental factors and revealed that mean yields for sorghum and wheat with NT were greater than with CT. They also recorded that soybean and wheat grown on sandy soils using NT had larger downside yield risks associated with NT than with NT on loamy soils, supporting the hypothesis that soil and climate factors significantly impact NT yields.

3.5 Agronomic Interventions for Increasing Crop Productivity in no-till

3.5.1 Sowing into Crop Residues

Maintaining crop residues on the soil reduces the exposure of the surface soil to natural elements and soil erosion is reduced drastically. However, sowing into crop residues can cause planting challenges related to seed placement. Challenges of NT include either retrofitting planting equipment or buying new specialized ones. However, the advent of seed drills that can help plant in the residue drilling at specified intervals makes adoption of NT a greater possibility. DeHate (2017) opines that the planter has to do more work to get the seed where it needs to be, and therefore NT planters need to have more down pressure and be a better equipment to clean the row right in front of where the seed needs to be dropped in the soil.

3.5.2 Cover Cropping Practices

No-till farming is implemented to a greater extent by organic farmers. In a continuous NT farming, weeds are controlled by herbicides rather than by tillage. However, this may lead to the development of herbicide-resistant weeds, as well as pesticide residue runoff into water as infiltration is improved under NT. However, in organic NT, the use of herbicides is not an option, and cover cropping is one major recommendation for weed control and yield improvements through NT; cover crop mulch-based NT production is emerging as an innovative alternative production practice (Vincent-Caboud et al. 2017). The main crop here is seeded into the residues of the terminated cover crops (CCs). The different methods by which cover crops are integrated into the organic NT systems can be studied from Fig. 3.1 incorporated here. However, in the USA, CCs were in use on less than 2% of total cropland (for all crops) during 2010–2011 (608 million acres) (USDA ERS 2017). Wade et al. (2015) noted that during 2010–2011, in the USA, approximately 4% of farmers adopted CCs on some portion of their fields, and only 1.7% did so, on cropland. In organic NT systems, NT planting is not continuously used for each crop but only for some of the main crops in the rotation like corn, soybeans, or vegetables (Rodale Institute 2011). No-tillage systems have also not been widely adopted in Europe despite the potential benefits of integrating NT into organic systems (Peigne et al. 2015).

Hepperly et al. (2008) reported that when the use of CCs intensified, they can effectively substitute for chemical inputs by providing effective weed control and even adding nutrients to soil reducing the cost and energy of fertilization substantially. Figure 3.2 shows the effect of CCs in increasing crop yields from a Rodale Farming Systems Trial.

Cover crops fall under different groups: cereals like oats, barley, triticale, and winter rye that produce very high biomass; legumes like sunn hemp, winterpea, cowpea, berseem clover, phacelia that are able to fix atmospheric nitrogen and improve the soil nutrient status; and brassica like the radish that has deep taproot

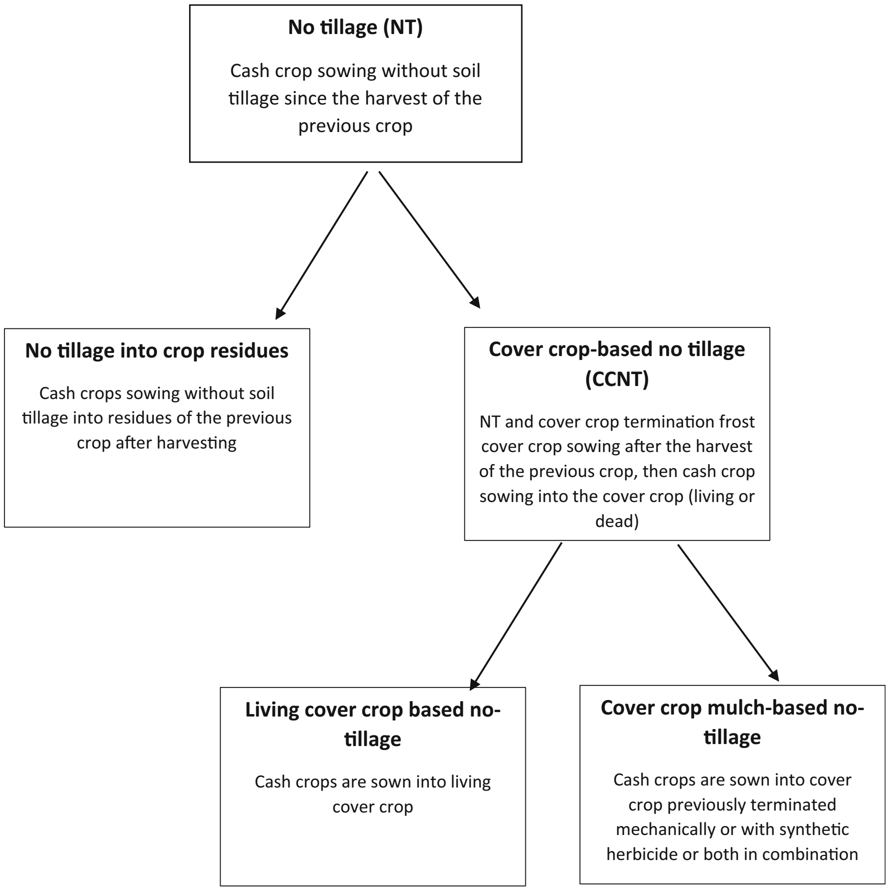

Fig. 3.1 Diagram of different techniques of no-tillage and cover crop management (Adapted from Vincent-Caboud et al. 2017)

system and helps improve soil porosity. The CCs can be grown as sole crop, in mixtures, or in sequence to build the soil and prevent erosion. Synergistic and antagonistic reactions have also been reported on growing CCs in sequence (Shekinah and Stute 2019).

3.6 Cover Crop and its Influence on Crop Yield

The success of cover cropping for NT depends on achieving a dense weed-free stand that will produce high amounts of biomass to provide subsequent nutrients and also keep away weeds in the main crop because of the biomass residue on the ground. Towards this end, it is very important to keep the date of planting CCs early as planting dates have an impact on the quantity of biomass produced, which in

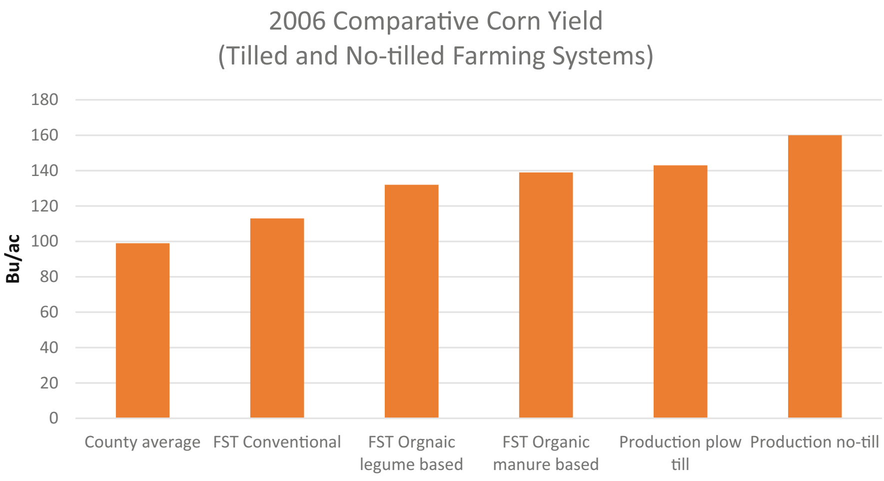

Fig. 3.2 2006 comparative corn yield (tilled and no-tilled farming systems). Rodale Institute Farming Systems Trial; yield in Bu per acre (Adapted from Hepperly et al. 2008)

turn also affects the nutrient addition and weed management. In date of planting studies in Wisconsin with sunn hemp, Stute and Shekinah (2019) reported that yield declined linearly from the initial date of planting (July 2), with a biomass decline of 1.3% per day and 8.9% per week. Care should be taken to ensure that the cover crop achieves maximum biomass as to form a mat of residue on termination. There are different ways to keep the CC residue on the soil forming a layer of mulch which conserves soil moisture and suppresses weeds. Mowing, undercutting, and rolling are methods that are used to terminate CCs. But it is imperative that the termination operations are done at the right time by adopting appropriate methods. Problems arise if the CC is in vegetative stage as it will continue to grow and interfere with the growing main crop. If it is far into the reproductive stage where it produces seed, then the CC will become a weed in the next cropping season. Maximizing agronomic benefits associated with CCs will depend on appropriate species choice and residue management (Ashford and Reeves 2003; Wortman et al. 2012a).

No-till cover crops greatly influence the yield of the main crop due to nutrient release, moisture conservation, and weed suppression, along with other tangible benefits like erosion control, improved soil structure, and infiltration. Reimer et al. (2012) stated that "potential yield increases associated with increased soil fertility were an economic motivation of CC adoption." No-till soybeans grown after rye termination with a roller crimper achieved similar yields as those in a chemically terminated CC while reducing residual weed biomass in Illinois (Davis 2010). Cover crops can help alleviate drought stress by potentially increasing infiltration rates and soil moisture content (Bergtold et al. 2017).

Economic considerations regarding the adoption of CCs are multifaceted. Inconsistent findings on the profitability of CCs and NT greatly influence adoption rates (Boyer et al. 2017). The producer has to consider direct benefits (yield and revenue increase), direct production costs, indirect benefits (i.e., possible savings), indirect opportunity costs, risks, and agricultural policy considerations (Bergtold et al. 2017). Clark et al. (2017) experimented with production systems which included tillage with no CCs, tillage with a mowed and incorporated CC (cereal rye, Secale cereale L.; and hairy vetch, Vicia villosa L.), and NT with a crimped CC in a wheat-corn-soybean rotation. Corn yield was reduced by 30% in NT plots with equal population which indicated that N immobilization may be significant in crimped CCs. Soybean and wheat were competitive under organic NT when soil moisture and weed control were adequate, which the authors suggested meant that adequate biomass of CC was crucial for competitive crop yields (Clark et al. 2017). Veenstra et al. (2007) have reported from various studies that apart from providing nitrogen, leguminous CC improve soil physical characteristics, reduce soil erosion, increase water infiltration, and increase crop yield potential and soil productivity.

Table 3.1 adapted from Blanco-Canqui et al. (2015) shows that the effect of CCs on crop yield in the USA has been variable. Their impacts on crop yields depend on annual precipitation, CC species (legume vs. nonlegume CCs), growing season (summer vs. winter CCs), tillage system (NT vs. CT), and number of years of CC management.

In Garden City, Kansas, Holman et al. (2012) concluded that CCs could be introduced during the fallow period with no reduction in the yield. Experiments found that winter and spring CCs and forage crops grown in place of fallow in a NT winter wheat-fallow system did not reduce the wheat yield but a winter triticale CC did reduce yields compared with fallow plots without CCs under NT management. Similarly, in Bozeman, Montana, Burgess et al. (2014) found that early termination of spring-planted annual legume CCs, such as pea and lentil used as green manure, did not reduce wheat yields. In semiarid regions, it has been observed that while CCs do not always reduce crop yields, at the same time, they do not necessarily increase crop yields. Under favorable climatic conditions, high biomass-producing and high N-fixing summer or tropical legume CCs such as cowpea, pigeon pea, and sunn hemp may have more rapid and greater effects on increasing crop yields and soil properties than winter CCs with low biomass input (Blanco-Canqui et al. 2012). Mahama et al. (2016) reported from a NT study in Kansas that the mean increase in grain yield as a result of including cowpea, pigeon pea, sunn hemp, double-cropped soybean, and double-cropped grain sorghum in the rotation over fallow with 0 kg N/ha was 78%, 91%, 66%, 72% and 12%, respectively.

Studies have indicated that crop yields increased as a result of adopting CCs in areas of high rainfall (Andraski and Bundy 2005; Balkcom and Reeves 2005; Blanco-Canqui et al. 2012). In south central Kansas, sunn hemp and late-maturing soybean as summer legume CCs increased crop yield when managed under a NT winter wheat–grain sorghum rotation under low N application (Blanco-Canqui et al. 2012). Sunn hemp increased the grain sorghum yield by 1.43 Mg ha^{-1} at 0 kg N ha^{-1}, by 0.67 Mg ha^{-1} at 33 kg N ha^{-1}, and by 0.58 Mg ha^{-1} at 100 kg N ha^{-1}, while it increased the wheat yield by 0.27 Mg ha^{-1} at 66 kg N ha^{-1} relative to plots without CCs.

Table 3.1 Cover crop effects on grain yield across different precipitation zones, soil types, tillage systems, and cover crop species

Study site	Precipitation (mm)	Soil structure	Tillage system	Cropping system	Cover crop planting time	Time after experiment start	Cover crops	Grain yield (kg ha^{-1})	References
Beltsville, MD	1192	Gravelly loam	No-till	Corn	Winter	1	No CC	7.7^{bc}	Decker et al. (1994)
							Hairy vetch	8.7^{a}	
							Winterpea	8.9^{a}	
							Crimson clover	8.1^{ab}	
							Wheat	7.2^{c}	
South Charleston, OH	1033	Silt loam	No-till	Corn	Winter	2	No CC	11.1 ns	Henry et al. (2010)
							Red clover	11.7	
						3	No CC	9.2 ns	
							Red clover	9.3	
Poplar Hill, MD	1009	Silt loam	No-till	Corn	Winter	Across 3 years	No cc	6.3^{b}	Decker et al. (1994)
							Hairy vetch	8.9^{a}	
							Winterpea	8.4^{a}	
							Crimson clover	8.7^{a}	
							Wheat	6.9^{b}	
Rock Springs, PA	1006	Silt loam	No-till	Corn	Winter	3	No CC	9.70 ns	Duiker and Curran (2005)
							Rye	10.02	
Columbia, MO	992	Silt loam	No-till	Corn	Winter	Across 3 years	No CC	$4.83^{a\text{-}d}$	Reinbott et al. (2004)

							Oat	4.56^{cd}	
							Hairy vetch	5.06^{ab}	
							Austrian winterpea	5.19^{a}	
							Hairy vetch + oat	4.88$^{a\text{-}d}$	
							Winterpea + oat	4.47^{d}	
				Sorghum			No CC	6.59^{b}	
							Oat	6.57^{b}	
							Hairy vetch	7.33^{a}	
							Austrian winterpea	7.06^{ab}	
							Hairy vetch + oat	6.94^{ab}	
							Winterpea + oat	6.64^{b}	
Hoytville, OH	859	Clay loam	No-till	Corn	Winter	2	No CC	6.2^{b}	Henry et al. (2010)
							Red clover	7.3^{a}	
						3	No CC	7.3 ns	
							Red clover	7.9	
Andover, SD	602	Loam	No-till	Corn	Fall	1	No CC	13.39 ns	Reese et al. (2014)
							CC mix	13.02	
						2	No CC	11.83^{a}	
							CC mix	10.07^{b}	

(continued)

Table 3.1 (continued)

Study site	Precipitation (mm)	Soil structure	Tillage system	Cropping system	Cover crop planting time	Time after experiment start	Cover crops	Grain yield (kg ha^{-1})	References
Akron, CO	428	Silt loam	No-till	Wheat	Summer	Across 6 years	No CC	3.92^{a}	Nielsen and Vigil (2005)
							Winterpea or field pea	2.64^{b}	
Trail City, SD	414	Loam	No-till	Corn	Fall	1	No CC	6.90 ns	Reese et al. (2014)
							CC mix	7.66	

Table adapted from Blanco-Canqui et al. (2015)
CC cover crop; *ns* non-significant; values followed by a similar letter are not significantly different while followed by different letters are

Table 3.2 Average cotton lint yields (kg ha^{-1}) by winter cover crop, tillage system, and N application rate from 1984 to 2012

N rate (kg ha^{-1})	No cover	Winter wheat	Hairy vetch
	Conventional till		
0	827 (276)*	745 (219	969 (299)
34	943 (295)	931 (266)	1084 (361)
67	1031 (345)	1034 (351)	1058 (369)
101	1106 (351)	998 (331)	1010 (365)
	No-till		
0	683 (267)	695 (222)	974 (321)
30	912 (274)	942 (248)	1074 (355)
60	1053 (344)	1055 (328)	1042 (370)
90	992 (363)	1038 (319)	947 (403)

Adapted from Boyer et al. (2018)
*Standard deviation in parentheses

When combined with improved management systems such as NT, CCs can enhance benefits of current NT compared to NT without CCs (Blanco-Canqui et al. 2011). Cover crop mixtures are considered more beneficial as different CCs can be expected to perform different functions at different layers of soil than a single species could. For example, mixing radish with rye can alleviate both soil compaction and soil erosion risks due to the bio-drilling potential of radish and abundant aboveground biomass cover produced by rye (Chen and Weil 2010).

The ecosystem services provided by CCs are also strongly interrelated. The figure adapted from Blanco-Canqui et al. (2012) shows interactions among soil physical, chemical, and biological properties and how it directly affects soil and water conservation, soil fertility, agricultural production, and environmental quality.

Increases in crop yields drive the profitability of NT planting because production costs of the two tillage systems (conventional and NT) are often similar due to investment costs on machinery in NT (Triplett and Dick 2008). Similarly for CCs, differences in net returns to NT and till planting have varied across studies (Hanks and Martin 2007; Triplett and Dick 2008; Zhou et al. 2017). Cotton lint yields in Tennessee over a period of 28 years have been compared with tillage systems and cover crops. The results (Table 3.2) showed that the cotton yield did not decrease due to cover cropping in NT (Boyer et al. 2018). However, there are other producer risks such as weed management and termination time that come into play when adopting NT or CCs. Cochran et al. (2007) made a significant finding, stating that tillage method made a difference in affecting cotton lint yields for all four cover alternatives (no cover, winter wheat, hairy vetch, and crimson clover). The interaction suggested that no-tillage significantly increased lint yields over time compared with conventional tillage and that the CC alternatives did not provide a great influence on the lint yield. Research in cotton indicates that any yield benefit derived from conservation tillage may not be seen until after multiple years of using the system (Triplett et al. 1996). Though NT with CC does not bring positive benefits every time, there are significant studies to suggest that NT does not decrease crop yields greatly and, over time, even builds up soil carbon and crop yield.

3.7 Cover Crop Management

What does a CC do that increases or at least helps maintain crop yield along with other ecosystem services under NT? The positive correlation of SOC with crop yields indicates that increase in SOC concentration with the addition of CCs is a determinant for the increase in crop yields (Blanco-Canqui et al. 2012). The addition of nutrients, especially N, when the chosen CCs are legumes, helps improve the soil nutrient base for increased crop yields. Senaratne and Ratnasinghe (1995) found that the growth and N yield of the commercial crop was positively correlated with the quantity of nitrogen fixed by the preceding legume crop. For organic farmers, alternating this practice (NT with CCs) with crops that are established with tillage avoids selection for perennial weeds (Rasmussen et al. 2014; Smith et al. 2011). CCs need to produce a biomass in the range of 5–8 t ha^{-1} in order to form an effective layer of mulch to prevent weeds from establishing (Mohler and Teasdale 1993).

When CCs are not harvested for a crop, the biomass they produce and the benefits gained by leaving it as a residue on the soil are many. But, CCs need to be terminated efficiently in a way that they do not present competition to the following cash crop. Termination method and residue management can influence N mineralization, soil availability, crop N uptake, weed communities, and soil moisture availability (Mirsky et al. 2009; Parr et al. 2011; Wortman et al. 2012b). Effective ways of termination of CCs can include use of herbicide sprays known as “burn-down” (Lu et al. 2000). A burn-down pass to terminate CC is unlikely to be an additional pass for a “NT” operator, as it is common to spray a nonselective herbicide prior to planting to terminate winter weeds (Bergtold et al. 2007). However, newer methodologies have been evolving to accomplish the same task without the introduction of harmful chemicals in the environment, especially in organic NT systems.

In the Midwest, if planted in August or September, following an early summer cash crop, it was best to simply let freezing temperatures terminate a sunn hemp crop. Many farmers have reported good success using crimping or mowing of sunn hemp as nonchemical methods of termination. Compared to mowing CCs, termination with a roller crimper reduces fuel and labor inputs, improves weed suppression by uniformly distributing residues, and prolongs residue decomposition (Creamer and Dabney 2002). The blades of the roller cause injury to the CCs accelerating the process of termination (Kornecki et al. 2006). This method does not disturb the soil and can be used alone or in conjunction with reduced rates of non-selective herbicide (Ashford and Reeves 2003). Moving toward the use of roller crimping for the termination of cover crops instead of herbicide applications can help to produce grain crops year after year without compromising on yields or soil erosion. Triplett and Dick (2008) argue that this form of roller crimping NT still requires surface disking of the soil during some seasons which reduces the NT’s ability to reduce soil erosion.

Growing of sunn hemp would therefore lead to NT corn if roller-crimped, with additional benefits of improved N status of the soil. Roller crimping may require multiple passes to sufficiently kill the CC. This system can greatly benefit organic NT corn while conventional farmers can also be benefitted by sunn hemp (Shekinah and Stute 2019). Clark et al. (2017) also reported that optimum time of CC crimping is important for acceptable weed control and was able to produce competitive yields in organic NT soybean and wheat. In Pennsylvania, Keene et al. (2017) found that minimizing CC seed production with strategic termination is critical in a rotational NT system of hairy vetch plus triticale-corn-cereal rye-soybean-winter wheat rotation. Slower decomposition of rolled residue also results in a longer period of weed suppression (Lu et al. 2000). Winter kill may be possible for less hardy CCs but result in lower level of biomass and less weed control (Mannering et al. 2000).

Yield results in organic NT are also dependent on past production history and CC stands. In an experiment at Rodale Institute, yields of 7–10 Mg ha^{-1} were achieved under favorable conditions with CCs (hairy vetch), while a yield as low as 1.1–3.4 Mg ha^{-1} was realized in other sites (Mischeler et al. 2010). Although rye mulch effectively suppressed weed growth in Wisconsin, rye regrowth competed with soybean (*Glycine max* L.) to reduce crop yield by 24% in organic NT treatments compared to tilled system (Bernstein et al. 2011).

Precedence must always be given to planting the cash crop. Bergtold et al. (2017) stated that giving additional 2 weeks for spring termination of hairy vetch could produce significant increases in the N accumulation and delaying winterpea termination by 18 days nearly doubles N contribution from 6.4 to 12.2 kg; however, if cash crop planting is done soon after termination, dying but not dead CCs will compete for soil nutrients and water.

3.8 Crop Rotation

Although organic production systems have been found to increase SOC pools over conventional tilled systems (Liebig and Doran 1999), a conventional NT system can also accumulate surface C compared to organic tilled systems with CC (Jokela et al. 2011). Cropping systems can influence SOC by the quality and quantity of residue returned to the soil (Sainju et al. 2007). Longer and more complex crop rotations can bring greater benefits including crop yield increases in a conventional system (Katsvairo and Cox 2000; Meyer-Aurich et al. 2006), increased soil quality (Karlen et al. 2006), and greater profits (Meyer-Aurich et al. 2006) although benefits are not consistently realized. However, in an organic system, where weed competitiveness and management is the major source of yield reduction, many studies found that increased rotation length and complexity can reduce weed population (Teasdale et al. 2004). Not much documentation is found on the benefits of crop rotation in organic agriculture of crop yields. Organic cropping systems that depend on cover cropping for weed management through soil coverage and nutrient supply through N fixation by use of leguminous CCs help improve or sustain crop yields in NT. Positive effects on soil physical, chemical, and biological properties have been found through the adoption of crop rotation involving cover cropping in NT farming. Selection of CC with strong and vigorous root systems is essential for the system to succeed (Garcia et al. 2013), and the CCs contribute to crop rotation diversification (Calonego and Rosolem 2010). The variable root systems of CCs (brachiaria and sorghum-sudan have large root systems, while sunn hemp and radish have fewer roots) break the compacted soil layers, while biomass increases the soil organic matter (SOM) and plays greater role in soil aggregation. Thus, the inclusion of CCs in a crop rotation, especially in a NT, plays an important role in improving soil properties that can enhance the commercial crop yields. Garcia et al. (2013) reported enhanced SOM and improved physical properties by growing crop rotations that included ruzigrass (*Urochloa ruziziensis*) grown in fall/winter, sunn hemp, sorghum-sudan grown in spring, and soybean as the summer crop under NT in a 3-year rotation. Increasing crop diversity and rotation length may have contributed to higher soybean yields in the 3- and 4-year systems compared with the 2-year system (Liebman et al. 2008). Mallarino and Ortiz-Torres (2006) noted that over a 21-year period in Iowa, no yield difference occurred for corn when the crop was grown at high N fertilizer levels in a 2-year rotation with soybean vs. when it was grown in a 4-year rotation sequence of corn-oat-alfalfa-alfalfa. In contrast, soybean yield was higher when that crop was grown in a 4-year rotation (soybean-corn-oat-corn) than in a 2-year rotation with corn.

Previous evaluations of organic rotational NT have demonstrated the weed suppression and reduced labor inputs compared to tillage-based organic management (Teasdale et al. 2012; Bernstein et al. 2011). Research at the Harvey County Experiment Field in Kansas over a 5-year period explored late-maturing soybean and sunn hemp and evaluated their effect on wheat-sorghum rotation in a NT condition. Averaged over N rate, wheat yields were 3.4 bu. ac^{-1} greater with CCs than with no CC in rotation, with notably increased yields under 60 kg N than 90 kg N when soybean was in the rotation. Similarly, sorghum produced 7.0 and 19.7 bu. ac^{-1} more in the rotations with soybean and sunn hemp, respectively, than in the rotation with no CC (Claassen 2008).

Practices such as organic no-till agriculture and perennial grain agriculture systems should be developed and prioritized for research (Margulies 2012). It is necessary to develop NT farming for any future role it will play in the development of sustainable agriculture. Problems associated with NT are those of pesticide and nutrient runoff and transport into water bodies. Working this out as an organic no-till system with cover crop or crop rotational practices for NT could help improve the system reducing the payload of the runoff along with greater control of soil erosion. In his paper, Margulies (2012) argues that while the earliest proponents of NT farming suggested that farmers would be best served in mimicking natural ecosystem processes to retain soil and suppress weeds, the result today is an agriculture that traded in the plow for pesticides and soil erosion for water contamination, the full consequences of which we may not know for some time.

3.9 Conclusions

Adoption of NT as a conservation strategy to prevent soil erosion can gain further traction if there are increased crop yields. Favoring that is the use of CCs in rotation with a clear indication of when and where they fit in the rotation. Adoption of CCs under NT influences the yield of the main crop due to moisture conservation and weed suppression, nutrient addition, and release along with other tangible benefits like erosion control, improved SOC, soil structure, and infiltration. Cover crops, when combined with improved management systems such as NT, can enhance benefits of NT compared to NT without CCs. A leguminous CC also fixes atmospheric nitrogen and improves the nutrient status of the soil. In fact, CC mixtures are considered more beneficial as different CCs can be expected to perform different functions at different layers of soil than a single species. Combination of CCs also help to alleviate both soil compaction and soil erosion risks due to biological tillage and also abundant aboveground biomass that enriches organic carbon in soil. Moreover, the ecosystem services provided by CCs are also strongly interrelated. CCs strongly influence the interactions among soil physical, chemical, and biological properties, and it directly affects soil and water conservation, soil fertility, agricultural production, and environmental quality. Research that is innovative and balances conservation of soil with increased crop yields and reduction in the exposure to potentially harmful herbicides and pesticides in water sources should be one of the best serving options that need to be developed on a larger consistent scale. Under such compulsions, it is fairly obvious and influential to turn to biological systems like the use of cover cropping, small grain cropping, and crop rotations to make no-till farming successful and sustainable.

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